Modelling Environmental & Economic Impacts of Aviation

Introducing the Aviation Integrated Modelling Project

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Motivation

• Global air transportation system continues to grow

• System is large, complex and multi-disciplinary involving numerous stakeholders with different agendas

• Range of future trends
  - Developing regions
  - Developing sectors
  - Developing technologies

• Increasing environmental pressures

• Need for tools to assist policymakers…
Aviation Integrated Modelling (AIM)

**Goal:** Develop policy assessment tool for aviation, environment & economic interactions at local & global levels, now and into the future

- Assess policies to strike appropriate balances between economic benefits and environmental impact mitigation
- Independent & transparent tool for mediating between stakeholders
AIM Architecture Benefits

- **Integration**
  - Captures interdependencies, data transfer & feedback
  - Examination of trade-offs (e.g. local environment vs. global environment vs. economic impacts)

- **Modularity**
  - Resolution of modules tailored to application
  - Subset of modules run independently
  - Substitution of models from other groups

- **Extendability**
  - Natural expansion in sophistication or number of modules

- **Policy assessment potential**
AIM Detailed Architecture

Global Environment Impacts

Local Environment Impacts

Local/National Economic Impacts

Institute for Aviation and the Environment

Version: 14 September 2007
AIM Detailed Architecture

Institute for Aviation and the Environment
Aircraft Technology & Cost Module

- **Goal:** Model aircraft performance, fuel use, emissions and operating costs for different technologies
Air Transport Demand Module

- **Goal**: Forecast future passenger & freight demand for air travel between global origin-destination city-pairs

![Diagram of Air Transport Demand Module](image-url)

- **Aircraft Technology and Cost Module**
  - Air Transportation Demand Module
    - Passenger Demand Forecasting
    - Freight Demand Forecasting
  - Optimize routing?
    - Yes: Scaled Airport Choice
    - No: Scaled Routing Model
  - Pax/Freight flow by OD city-pair
  - Delays by OD city-pair

- **Regional Economics Module**
  - Pax/Freight flow by Airport
  - Technology cost
• **Goals:** Forecast air traffic growth as function of demand; and airport operations/congestion as function of air traffic.
Aircraft Movement Module

• **Goals:** Identify location of emissions released from aircraft in flight; Predict airborne delay characteristics
AIM Detailed Architecture
Global Climate Module

- **Goals**: Determine impact of aircraft emissions on the global climate system \((\text{CO}_2, \text{NO}_x, \text{SO}_x, \text{H}_2\text{O})\)
• **Goals:** Investigate dispersion of critical pollutants (NO$_x$, PM, O$_3$) and noise impacts in airport vicinity

**Local Air Quality & Noise Module**

- **Meteorology Parameterization**
- **Source Pre-processing**
- **Industry Noise Model**
- **Dispersion Model**
- **Atmospheric Chemistry Model**

**Local Environment Impacts**
- **LAQ:** NO$_x$, NO$_2$, PM$_{10}$, PM$_{2.5}$ concentrations
- **Noise:** Contours/population impacts for metrics of choice

**Regional Economics Module**
Regional Economics Module

- **Goals:** Quantify positive and negative economic effects of air transport activity on surrounding regions
US aviation system evolution scenarios

- **Scenario 1: Unconstrained**
  - No feedback of effects of delay: demand and operations grow unconstrained by system capacity

- **Scenario 2: Feedback of Delay**
  - 50% of delay-induced operating cost increase fed back in ticket price, increasing travel cost and reducing demand

- **Scenario 3: Feedback of Delay plus Per-Km Tax**
  - As Scenario 2, but per-km tax policy designed to reduce 2020 demand to 2000 levels
Demand, Operations, Delay & NO\textsubscript{x} Results

**Demand** (a)

**Aircraft Operations** (b)

**Arrival Delay** (c)

**ORD Total NO\textsubscript{x}** (d)

Assumed airport capacity increase
Demand/Ops/Delay Results Discussion

• Importance of feedback of delay effects
  - 20% reduction in demand in 2030 with Scenario 2
  - 15% reduction in operations in 2030 with Sc. 2
    - Less than demand reduction: higher proportion of smaller aircraft
  - 50% reduction in average arrival delay in 2030 with Sc. 2
    - Highly non-linear behaviour of delay with operations, especially when close to capacity

• Policy analysis provides interesting insights
  - High per-km tax required to reduce demand to 2000 levels
    - 7.7 cents/km equates to $300 extra New York-Los Angeles
  - Demand falls to 2000 levels but operations fall less
    - Short haul demand less sensitive to price increases (business pax)
    - Higher proportion of short-haul traffic after policy introduction
En Route CO\textsubscript{2}/Global RF Results

Baseline (2000)

Scenario 1 (2030)

Scenario 2 (2030)

Scenario 3 (2030)

Global RF\textsubscript{aviation} = 25.4 mW/m\textsuperscript{2}

Global RF\textsubscript{aviation} = 33.8 mW/m\textsuperscript{2}

Global RF\textsubscript{aviation} = 31.5 mW/m\textsuperscript{2}

Global RF\textsubscript{aviation} = 26.8 mW/m\textsuperscript{2}
En Route CO$_2$/RF Results Discussion

• Compared to Baseline Emissions…
  - Large increase in Scenario 1 en route emissions
    - Concentration in heavily-travelled trans-continental routes
  - Smaller increase in Scenario 2 en route emissions
    - From dampened demand and operations
  - Evidence of emissions increase in Scenario 3
    - Demand creeps back 10 years after introduction of policy

• Global radiative forcing perturbation analysis shows similar trends
  - Scenario 1 up 8.4 mW/m$^2$ by 2030, Scenario 2 up 6.1 mW/m$^2$, Scenario 3 up 1.4 mW/m$^2$ relative to baseline
    - 25.4 mW/m$^2$ in 2000
ORD Annual Average NO$_x$ Results

Baseline (2000)

Scenario 1 (2030)

Scenario 2 (2030)

Scenario 3 (2030)
• Rapidity of LAQ algorithm allows a large number of airports to be modelled – case study focus on ORD
  - NO$_x$ concentrations reflect prevailing winds and current/predicted runway usage
  - Taxi and terminal area emissions dominate over runway emissions as delays increase

• Probability of violating current NO$_2$ regulations in Scenario 1 and 2
  - Policy measures may be required to avoid this
  - Emissions increase due to increased operations and delays, so capacity increases produce temporary improvement
Sample Future AIM Developments

• Modelling world passenger and freight demand
  - Focus on developing regions, e.g. S and E Asia
  - Business vs. leisure consideration
  - Passenger mode choice

• Airline response model
  - Capture effects of airline schedule/routing/fleet modification behaviors with changing operating environments

• Modelling of future aircraft/engine technologies and their likely introduction to system
  - Incremental designs: higher efficiency
  - Novel configurations: open rotor engines, blended wings
  - Alternative fuels
Conclusions

- AIM developing policy assessment tool for aviation, environment and economic effects
- Breadth and depth of model presented
- Case study results demonstrate utility of approach
- Future enhancements planned
# AIM Team

## Core team:
- Dr. Andreas Schäfer (*Principal Investigator*)
- **Steven Barrett** (*Local Air Quality & Noise*)
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- Antony Evans (*Airport Activity*)
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